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Aerodynamics of baseball

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Abstract

Baseball is one of the popular games in America, North Asia and some parts of Europe and Africa. Despite being a popular game, scan data is not available on aerodynamic properties of baseball. Having over 108 curved stitches, complex seams and their orientation, the airflow around the ball is significantly complex and little understood. The primary objectives of this study were to evaluate aerodynamic performances of a commercially manufactured baseball. The aerodynamic forces and moments were measured experimentally for a range of wind speeds and seam orientations. The aerodynamic forces and their non-dimensional coefficients were analyzed.

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Keywords: Baseball; aerodynamics; drag; wind tunnel; experimental measurement

1. Introduction

The flight trajectories of sports balls largely depend on the aerodynamic characteristics of the balls. Depending on aerodynamic behavior, the ball can be deviated significantly from the anticipated flight path resulting in a curved and unpredictable flight trajectory. Lateral deflection in flight, commonly known as swing, swerve, curve or knuckle, is well recognized in cricket, football, golf, tennis and volleyball. In most of these sports, the lateral deflection is produced by spinning the ball about an axis perpendicular to the line of flight or by other means to make asymmetric airflow around the ball. Therefore, the aerodynamic properties of a sport ball is considered to be the fundamental for the players, coaches (trainers), regulatory bodies, ball manufacturers and even the spectators. It is no doubt that baseball is widely recognized as the national sport of the United States. It is at all levels (professional,

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amateur, and youth) now popular in North America (USA, Canada, Mexico, Cuba), parts of Central and South America and the Caribbean, Japan, South Korea, Australia, New Zealand, and many other parts of Asia, Europe and Africa. Like sphere, the baseball is not uniformly smooth or rough but is characterized by the yin—yang pattern of raised approximately 108 stitches which makes the airflow around the ball one of the most complex and unpredictable [2]. Although the aerodynamic behaviour of other sports balls have been studied by Alam *et al.* [3, 4], Asai *et al.* [7], Mehta [9], and Smits and Ogg [11], scant and reliable experimental data is available to the public domain about the aerodynamic behaviour of baseball except some studies by Adair [2], Alaways [6], Kensrud [8] and Nathan [10]. Therefore, the primary objective of this work is to experimentally study the aerodynamic properties of a commercially made baseball used in major tournaments in Australia.

Nomenclature

F_D	Drag Force
C_D	Drag Coefficient
Re	Reynolds Number
V	Velocity of Air
μ	Dynamic Absolute Viscosity of Air
ρ	Density of Air
d	Diameter of the baseball

2. Experimental Procedure

A brand new commercially made baseball has been selected for this study. The ball was manufactured by Easton approved by Baseball Australia. The ball model is 600. The outer surface of the ball is made of leather and the ball diameter is approximately 72 mm. The side views of the ball are shown in Figures 1 for different positions.

In order to measure the aerodynamic properties of the baseball experimentally, the RMIT Industrial Wind Tunnel was used. The tunnel is a closed return circuit wind tunnel with a maximum speed of approximately 150 km/h. The rectangular test section's dimension is 3 m (wide) x 2 m (high) x 9 m (long), and is equipped with a turntable to yaw the model. The balls were mounted on a six component force sensor (type JR-3) and purpose made computer software was used to digitize and record all 3 forces (drag, side and lift forces) and 3 moments (yaw, pitch and roll moments) simultaneously. More details about the tunnel can be found in Alam *et al.* [5].

A support system previously developed for tennis and cricket balls was used to hold the baseball on a force sensor in the wind tunnel, and the experimental set up with the support system in the test section of RMIT Industrial Wind Tunnel is shown in Figure 2. The support device can also spin the ball with a maximum rotational speed of 3500 rpm. The aerodynamic effect of the support device was subtracted from the support with the ball. The distance between the bottom edge of the ball and the tunnel floor was 400 mm, which is well above the tunnel boundary layer and considered to be out of ground effect completely.

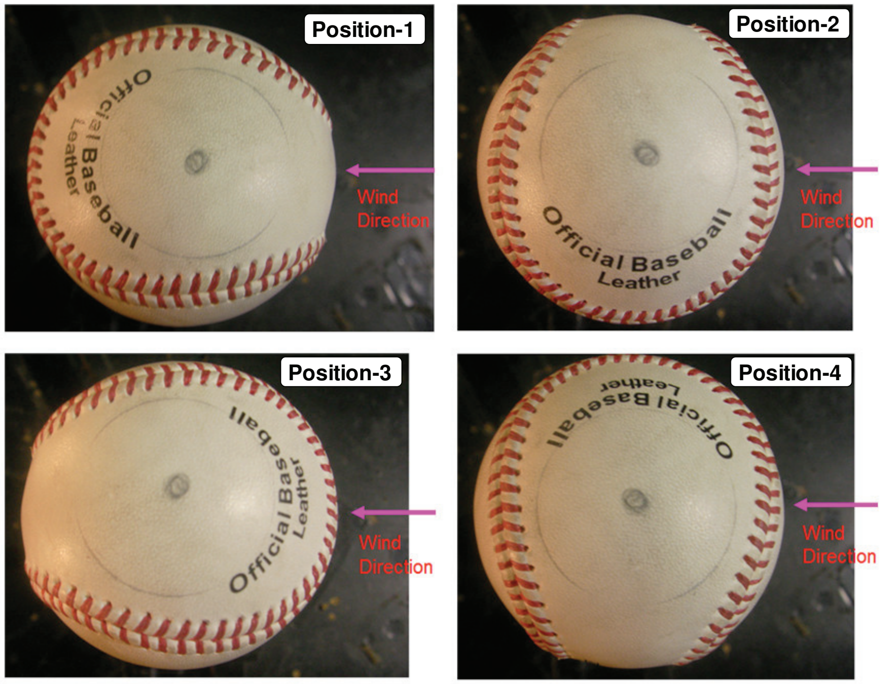

Fig. 1. Test configurations of the Easton made baseball

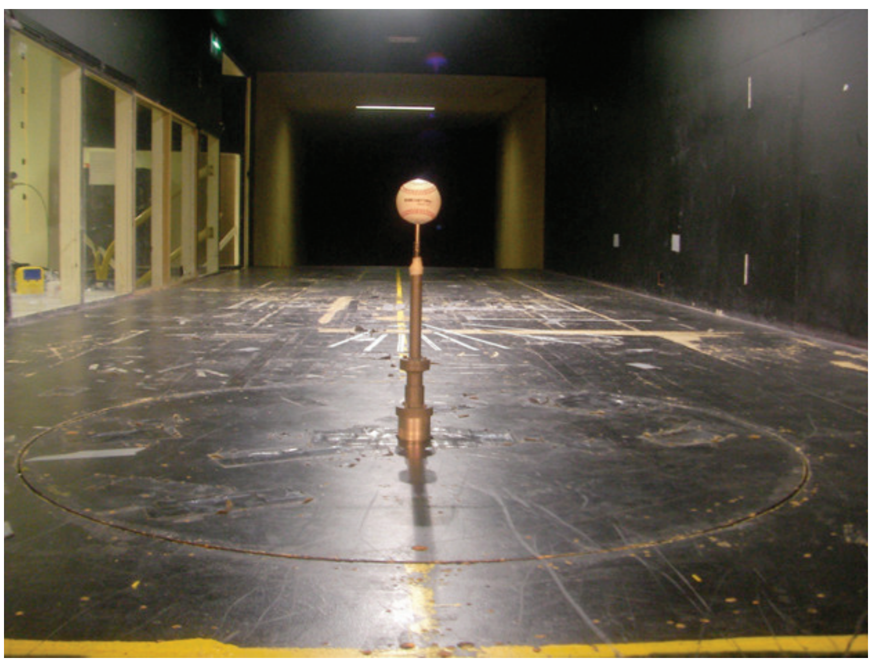

Fig. 2. Experimental setup for wind tunnel testing of soccer balls

The aerodynamic drag coefficient (C_D) is defined as: $C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$, where F_D, ρ, V & A are drag, air density, wind velocity and projected frontal area of the ball respectively. The Reynolds number (Re) is defined as: $Re = \frac{\rho V d}{\mu}$, where ρ, V, d & μ are the air density, wind velocity, ball diameter and the air absolute dynamic viscosity respectively. The lift and side forces and their coefficients were not determined and presented in this paper. Only drag coefficients are presented in this paper.

3. Results and Discussion

The baseball was tested at 30, 40, 60, 80, 100, 120 and 140 km/h speeds. However, the results shown here are for 60 km/h to 140 km/h. The aerodynamic force was converted to non-dimensional parameter (drag coefficient, C_D) and tare forces were removed by measuring the forces on the sting in isolation and removing them from the force of the soccer ball and support system. The influence of the support on the ball was checked and found to be negligible. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than 0.5 km/h. As a baseball possesses rough and curved stitches on its surface, the aerodynamic behavior will differ for different orientations of the ball. Additionally, different sectors of the stitching will influence the airflow differently and generate induce drag at different velocities. In order to get some insights into it, the baseball has been tested at four seam orientations facing the oncoming wind in the wind tunnel. These four orientations are shown in Figure 1.

The C_D variations with Reynolds numbers for all four seam positions are shown in Figure 3. The C_D value variations among four positions are evident at low Reynolds number ($Re = 1.6 \times 10^5$ however, these variations are minimal at high Reynolds numbers, is believed to be due to the elimination and/ or minimization of local flow separations from seams. The average C_D value for all four positions is approximately 0.62 which slightly higher compared to published data [2]. It is believed that most of the published data was obtained using a low turbulence smooth wind tunnel whereas the turbulence intensity of RMIT Industrial Wind Tunnel is around 1.8%. The flow transition is not clearly evident under the range of speeds tested in this study however, a minor transitional effect is evident at $Re = 1.4 \times 10^5$. According to Adair [2], the baseball does not display a notable transitional effect like a smooth sphere due to the presence of its complex seams and stitches. Our data agrees well with the findings of Fuss [12] where the author clearly states that the surface skewness has notable effects on the airflow transition (e.g. minor transitional effect) especially for the base ball and tennis ball. As mentioned earlier, the effects of seam and stitches are evident at low speeds as the local flow separation is generated due to seams, stitches and their complex orientation. Nevertheless, these local flow separations disappear or minimize at high speeds thus reducing the effects of seams and stitches. The seam position 4 has the highest effect compared to other seam positions whereas the seam position 2 has the lowest average C_D value. The average C_D values for each of these four positions starting from position 1 are 0.61, 0.62, 0.63 and 0.65 respectively. Further study is underway to visualise the airflow around the baseball and will be reported in the subsequent publications.

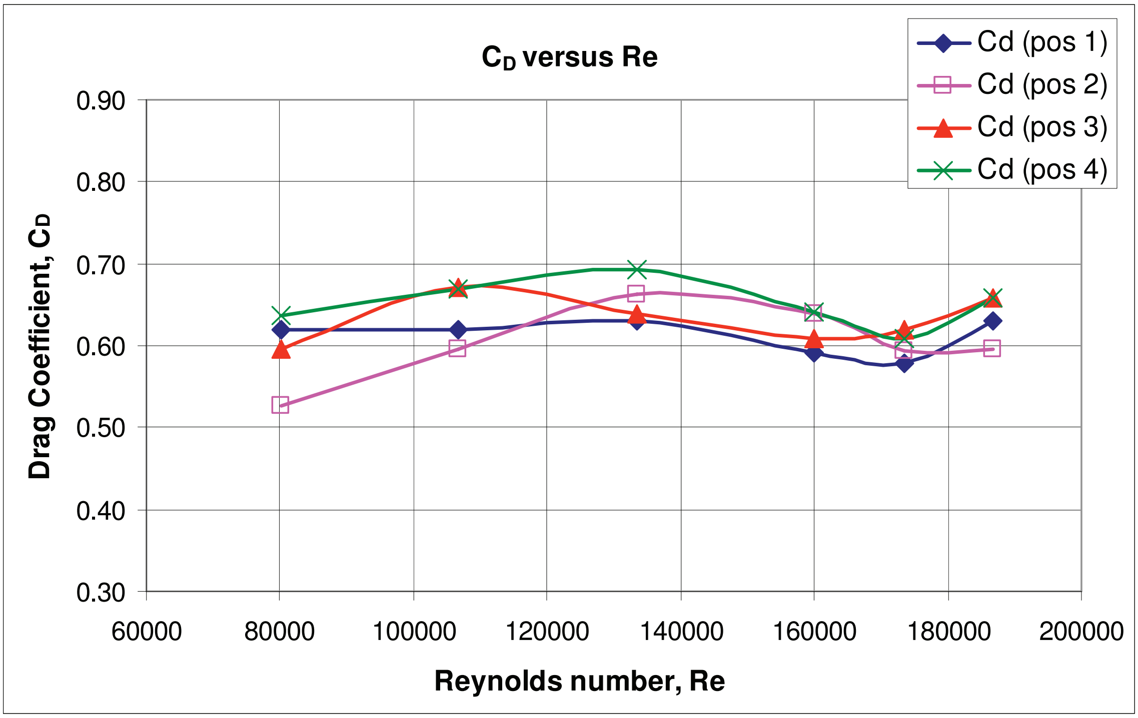

Fig. 3. Drag comparison for different baseball orientations.

The baseball is usually played at speeds greater than 100 km/h. The asymmetric forces can be considerable for baseballs due to the complex seam orientation, stitches and most importantly due to spin. These asymmetric forces deviate the flight path of the ball so sharply that it is almost impossible to hit and catch. However, the most skilful pitcher has great difficulty in throwing the ball with the precision required to generate a reproducible break. As a result, the behavior of the ball often surprises everyone - batter, catcher and pitcher. Therefore, it is utmost important to understand the complex aerodynamics of the base ball under spinning and non-spinning conditions. In this study, as mentioned earlier, only no-spinning condition data is presented. Further study is underway to investigate the spin effects on baseball aerodynamics.

4. Conclusions

The following conclusions have been drawn from the experimental study presented here:

- The average C_D value for a baseball obtained in this study is around 0.62.
- Seam orientation and stitches have significant effects on baseball aerodynamics at low Reynolds numbers however these effects are minimal at high Reynolds numbers.
- No significant transitional effect is evident in the baseball CD value.
- The variation of CD value between sides of a baseball facing the wind can vary be up to 8%.

5. Future Work

- Airflow around a base ball will be visualised.
- Effects of spin on aerodynamic properties will be undertaken.

Acknowledgements

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